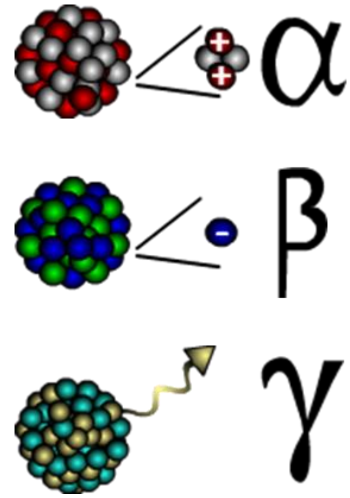
NATURALLY-OCCURRING RADIONUCLIDES

What are they?

Radionuclides are radioactive atoms. It is possible for radionuclides to be manmade, as is the case with some materials from nuclear power reactors, but they also occur naturally in rock formations and are released to groundwater over millions of years by geochemical reactions. Common naturally-occurring radionuclides in groundwater include uranium and thorium, which both decay to different forms of radium, which in turn decays to radon.



Alpha, beta, and gamma types of radiation. *Figure: US EPA*.

There are no NR 140 groundwater quality standards for radionuclides in Wisconsin but drinking water at public water systems is monitored for general indicators of radioactivity (alpha, beta, gamma activity) and for specific radionuclides (uranium, radium).

Maximum contaminant levels (MCLs) in public drinking water systems have been established for radionuclides at 15 picocuries per liter (pCi/L) for alpha activity, 4 millirems per year (mrem/yr) for beta or gamma activity, 5 pCi/L for total radium (radium−226 and radium−228), and 30 micrograms per liter (ug/L) for uranium (WI NR 809.50-809.51). People who drink water containing alpha, beta or gamma radiation, or radium or uranium in excess of established MCLs, over many years, may have an increased risk of getting cancer. In the case of uranium, an increased risk of kidney toxicity is possible as well. There is no public drinking water standard for radon, although the United States Environmental Protection Agency has proposed that radon levels be no higher than 4,000 pCi/L where indoor air abatement programs for radon exist, or 300 pCi/L where indoor air radon abatement programs do not exist.

Occurrence in Wisconsin

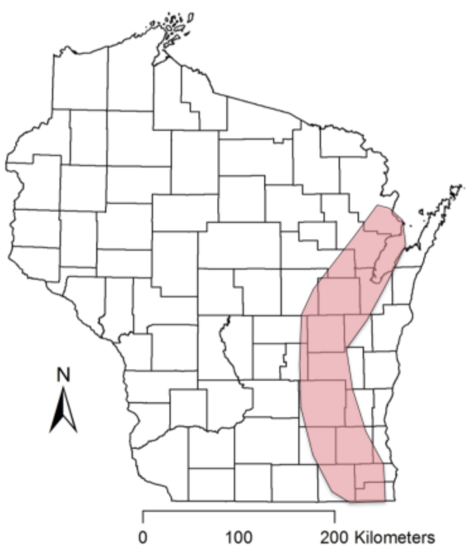
Radionuclides occur naturally in rock formations, and every well in Wisconsin contains some level of dissolved radionuclides. In most places these levels are not concerning, but some areas of the state tend to have notably high concentrations of radium, radon, and/or gross alpha activity.

In *northern Wisconsin*, there are notably high levels of both radon and gross alpha activity. Here, the geologic source is usually granite bedrock or, in some cases, granitic sand and gravel deposits.

In *eastern Wisconsin*, wells that draw from a very deep sandstone aquifer, the Cambrian-Ordovician, to the east of where it underlies another geological formation, the Maquoketa shale, often have levels of radium above the MCL. This band of high radium activity stretches from Brown County in the north to Racine County in the south and primarily affects public wells, since drilling deep enough to reach this aquifer is usually prohibitively expensive for smaller private systems. The geochemical explanation for the high radium levels is that the solubility of radium is related to the solubility of sulfate minerals in this aquifer, and the sulfate minerals that are common to the east of the Maquoketa shale are more soluble than those to the west of the Maquoketa due to confined conditions and geochemical differences.

About 80 public water systems have exceeded a radionuclide drinking water MCL standard at some point in time. The DNR has been working with these systems since 2003 to ensure that they develop a compliance strategy and take corrective action, so currently less than 10 remain that are providing water in excess of established radionuclide MCLs.

GCC Agency Actions



Area of Wisconsin where most of the wells that exceed the drinking water MCL for radium are located. This band coincides with where the Cambrian-Ordovician sandstone aquifer underlies the Maquoketa shale. *Figure*: *Luczaj and Masarik, 2015*.

By the mid-1980s, regular monitoring of public water supplies in north central Wisconsin seemed to indicate that there was an increased risk of radionuclide contamination in wells drawing from the granite bedrock aquifer. This raised concern since, at the time, drilling to this deeper granite aquifer was viewed as the best alternative if wells in the shallow sand and gravel aquifer became contaminated by manmade sources. After collecting and analyzing nearly 500 samples from this area in the late 1980s, the DNR showed that the granite bedrock aquifer is indeed a significant source of radionuclides, especially *radon*, and the DNR began taking steps to educate well owners and expand the investigation. Follow up work in other regions of the state by the DNR, WGNHS, and DHS also showed that while nearly all aquifers in the state contain some amount of radon (at or above 300 pCi/L), exceedingly high levels (over 4,000 pCi/L) are only found in granite or in sand and gravel deposits derived from granite (Mudrey and Bradbury, 1993). A few studies by University of Wisconsin researchers at this time also noted that unusually high levels of *radium* in eastern Wisconsin seemed to be related to the Maquoketa shale formation (Taylor and Mursky, 1990; Weaver and Bahr, 1991).

In the early 2000s, the flow patterns and geochemistry of groundwater in southeastern Wisconsin became of great interest as large-scale pumping driven by growing communities outside Milwaukee began to dramatically change groundwater conditions. One puzzle to scientists was why *radium* levels were elevated to the east of the Maquoketa shale in this region but not to the west – conventional understanding of the sources of radium did not seem sufficient to explain observations. Leveraging new models and knowledge about groundwater flow patterns in the Waukesha area, researchers at the University of Wisconsin and WGNHS, funded by the Wisconsin Groundwater Research and Monitoring Program (WGRMP), elucidated the relationship between radium and sulfate minerals in the area, collecting much needed information on the geochemical backdrop of the region in the process (Grundl and Cape, 2006; Grundl et al. 2006).

A study of radium in groundwater, in the Cambrian-Ordovician aquifer system, was conducted in the vicinity of Madison in 2016 - 2017 (Mathews et al. 2019). This study evaluated radium occurrence in groundwater relative to several geochemical parameters, as well as the presence of naturally occurring radium "parent elements", uranium and thorium, in aquifer bedrock units. The Cambrian-Ordovician aquifer in central Wisconsin is composed of an unconfined bedrock aquifer unit and a confined bedrock aquifer unit, separated by the Eau Claire shale aquitard.

Radium parent radionuclides (^{238}U and ^{232}Th) were found associated with both the Eau Claire shale aquitard and bedrock layers in both unconfined and confined Cambrian-Ordovician aquifer units. The study found an association in the upper, unconfined aquifer unit, between elevated levels of radium in groundwater and relatively high levels of total dissolved solids (TDS). High TDS in groundwater, creating competition between radium and other dissolved ions for sorption sites, is proposed as the explanation for the elevated groundwater radium found in the unconfined aquifer unit. Elevated groundwater radium in the lower, confined aquifer unit was found to be associated with very low groundwater dissolved oxygen (DO) levels. Dissolution of iron and manganese hydroxide radium adsorption sites occurs under low DO conditions and adsorbed radium can be mobilized into groundwater under those geochemical conditions.

The Wisconsin State Laboratory of Hygiene and other WGRMP-funded researchers have also made advances in sampling techniques and laboratory testing for radionuclide parameters, which tend to be very sensitive to collection and analysis methods. These studies have demonstrated how simple differences in approaches can cause one analysis to conclude a water sample is below the MCL while another can conclude the opposite about the same sample (Sonzogni et al., 1995; Arndt and West, 2004). Following these findings, researchers have developed corrections and guidelines to ensure reported test results are as accurate as possible.

Future Work

The DNR continues to work with public water systems that exceed drinking water standards for radionuclides to bring them into compliance. Options include blending water high in radionuclides with water from sources containing lower levels of radionuclides, finding an alternative water supply or constructing a new well in a low radionuclide aquifer, and softening or applying another effective radionuclide removal treatment technique to the water supply. The need for compliance with radium drinking water standards is the main reason the city of Waukesha sought, and received approval under the Great Lakes Compact, for diversion of Lake Michigan water.

Further Reading

DHS resources for contaminants in drinking water

DNR overview of radium in drinking water wells

DNR overview of radon in drinking water wells

WGNHS report on distribution of radionuclides in groundwater

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